Submillimeter-Wave Radiometer and Spectrometers using Cryogenically Cooled HEMT Amplifier Front-Ends

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Radiometric and high-resolution spectroscopic studies at submillimeter-wave frequencies play a very important role in the Earth science, astrophysics, and planetary exploration. Its importance is underscored by the key role of heterodyne spectrometers in the ESA cornerstone Herschel Space Observatory, NASA's Microwave Limb Sounder (MLS) instrument on Earth Observation System (EOS) Aura satellite, NASA's Microwave Instrument on the Rosetta Orbiter (MIRO), as well as the ground-based Atacama Large Millimeter Array (ALMA), and airborne Stratospheric Observatory for Infrared Astronomy (SOFIA).

Traditionally, where highly sensitive measurements are the prime requirement, superconductor-insulator-superconductor (SIS) mixer based receivers cooled to 4K temperature were used at the front-end of the submillimeter-wave radiometer and spectrometers. When cryogenic cooling is not an option, Schottky diode based receivers operating at the room temperature were the obvious choice for these applications as there were no amplifiers available at the submillimeter wavelengths. However, InP high electron mobility transistor (HEMT) based amplifiers and mixers are now available at these frequencies. At submillimeter-wavelengths, low noise amplifiers with substantial gain at the front-end will reduce noise contribution from mixers and intermediate frequency (IF) amplifiers. Moreover, power amplification available through these devices would significantly improve local oscillator (LO) efficiencies. Cryogenic cooling of these amplifiers to 20K provides sensitivity similar to SIS mixers. Although the noise temperature of the front-end HEMT amplifier cooled to 20 K might not be as close to the SIS mixers, however, the 20-30 dB gain it will provide at the front of the mixers and IF amplifiers will provide system noise temperatures similar to a SIS based system, without a 4 K cooling system. Moreover, the sensitivity to physical temperature is much less for amplifiers than SIS. The amplifier receivers would still work at higher temperatures, though at a bit higher system noise, unlike the SIS receivers. Moreover, the higher operating temperature makes these amplifier receivers better suited to planetary instruments and earth remote sensing suborbital platforms where available power is scarce.

In the last few years, the development of transistor technologies with maximum device frequency (f_{MAX}) over 1 THz has pushed operating frequencies of amplifiers well into the 700 GHz range. Northrop Grumman Aerospace Systems (NGAS) has developed an ultra-short-gate-length HEMT process which has produced InP HEMT amplifiers working at 700 GHz and beyond. We have evaluated several of these amplifiers in the 300 GHz and 650 GHz band and cooled them to 20K. The amplifier noise temperatures were reduced by a factor of 8 to 10 when cooled to 20K from room temperature.

In this paper, we will discuss the science drivers and progress in the cryogenic HEMT amplifier based heterodyne receivers at submillimeter wavelengths and their potential for future spectroscopic and radiometric instruments.

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